The Role of Hydrogen in a Sustainable Energy Future

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Unclassified
What we need from our energy system

- Most Americans do not think about energy unless the lights go out or the price at the pump skyrockets.
- BUT, access to clean, reliable, affordable and sustainable energy is vital to maintaining and enhancing our standard of living.
What we need from our energy system

• Any energy system, even our current one, needs to have certain characteristics
  – Security of supply
    • Domestic production
    • Flexibility of sources
    • Sustainability
  – Environmental quality
    • Reduced harmful emissions (smog, particulates)
    • Low GHG emissions
    • Sustainability
  – Economic benefits
    • Efficient and reliable
    • Accessibility
    • Stable prices
    • Job creation
Two-thirds of oil is used in Transportation Sector. The rest is used to produce chemicals (Industrial Sector) and heating oil (Residential & Commercial).

Electricity for energy services (lighting, cooking, ventilation, cooling, computing, etc).
Natural gas for heating, cooking.
Current US Resource Base

- Petroleum: 40%
- Natural Gas: 23%
- Coal: 23%
- Uranium: 8%
- Renewables: 6%

Is this diverse enough?
Transportation Energy Use

Transportation Sector is 97% petroleum-based. Nearly 60% of the petroleum we use is imported, and the gap is growing with every day.
China’s oil imports have DOUBLED since the 2005 WEO report, and vehicle ownership continues to rise.
CO₂ Emissions per Capita

Notes: Data from IEA 2006 Key World Energy Statistics
USA included in OECD – also plotted separately to show contribution
Why Hydrogen?
It’s abundant, clean, efficient, and can be derived from diverse domestic resources.
What is Hydrogen?

- Element 1 on the Periodic Table
  - 1 proton, 1 electron
- Diatomic molecule (H₂)
  - 2 protons, 2 electrons
- Highest energy content of common fuels on a WEIGHT basis
- Lowest energy content of common fuels on a VOLUME basis
- “H” is abundant on earth, but usually bound to carbon (such as CH₄) or oxygen (H₂O) or both (organic matter – “carbohydrates” – C₆H₁₂O₆)
- H₂ is not found in nature in large quantities (although there are some underground gas deposits that have relatively high concentrations of H₂)
Why Hydrogen?

• Flexibility of source: can be produced from a wide variety of domestically-available resources at any scale
  – Could reduce price instabilities in the energy market
  – All regions of the world are “in the game”
  – Energy security is actually possible through increased domestic energy production

• Significant, positive environmental impacts are possible
  – Remove energy production and consumption from the environmental equation, both locally and globally
  – Potential for very-low impact throughout energy chain
    • Urban air quality
    • Global climate change

• Flexibility of use: only energy carrier that can (effectively) provide all energy services for all energy sectors
Flexibility of Source

- Hydrogen can be produced from water; from carbon-containing materials (usually reacting with water); as a byproduct of chemical processes
- Regional variations in traditional energy resources are no longer an issue
- Every region has some indigenous fossil or renewable resource that can be used to make hydrogen
Sustainable Paths to Hydrogen

Solar Energy

- Heat
- Mechanical Energy
- Electricity
- Thermolysis
- Electrolysis
- Conversion
- Photolysis

Hydrogen
Renewable Resources

Composite Wind Resource Map

Annual Average Solar Resource
Flat Plate Collector Tilted at Latitude

Biomass Resources Available in the United States
Fossil and Uranium Resources
Production Potential from Domestic Resources

• As an example, how could the US fuel half of the current fleet with hydrogen?
  – Current annual consumption in the light-duty market is 16 quads of gasoline
    • Quad is short for Quadrillion \((10^{15})\) BTUs
    • One quad is about 8 billion gallons of gasoline, or about 230 million barrels of crude oil (making current consumption ~3.7 billion barrels of oil annually, for light-duty vehicles only)
  – Assume a 2x increase in efficiency with hydrogen fuel cell vehicles
  – For half of the fleet, we need 4 quads
  – This is 36 (let’s call it 40) million tons of hydrogen per year (~4 times the current domestic hydrogen production)

• Using only ONE domestic resource, can we make this much hydrogen?
  – We will, of course, use a combination of resources, but this is an interesting and eye-opening exercise
Production Potential from Domestic Resources

For 40 million tons/year of hydrogen, we would need:

95 million tons of natural gas (current consumption is around 475 million tons/year in all energy sectors)

OR

280-560 million tons of coal (current consumption is around 1,100 million tons/year)

OR

400-800 million tons of biomass (availability is 800 million tons/year of residue plus potential of 300 million tons/year of dedicated energy crops with no food, feed or fiber diverted)

OR

The wind capacity of North Dakota (class 3 and above)

OR

3,750 sq. miles of solar panels (approx. footprint of the White Sands Missile Range)

OR

140 dedicated conventional nuclear power plants
Hydrogen from Renewables
Per Area Potential
So We Can Produce Hydrogen - Now What?

• Storage of hydrogen on board a vehicle is a tough technical challenge
• Installation of a hydrogen delivery and dispensing infrastructure is an expensive proposition (maybe)
• It’s not just the transportation sector that is affected by hydrogen and fuel cells – need to pay attention to stationary and portable applications also
• To realize the benefits of a hydrogen economy, we actually have to put a value on energy security and environmental impacts, and bear some incremental cost
Hydrogen Storage Targets

Where do you think gasoline fits on this chart?
20 gallons of gasoline weigh about 56 kgs
The fuel system weighs about 74kgs = ~75%

56000 grams of fuel (20 gallons of fuel)
in a system volume of 107 liters (~28 gallons) = ~500 g/L
Hydrogen Distribution and Delivery

- Hydrogen distribution and delivery infrastructure exists today
  - Merchant hydrogen delivery as liquid or compressed gas
- Is it enough for a while?
- How long before we need more?
- At what cost, and for what coverage?
  - Estimates range all over the place, generally in the $Billions
  - Auto Companies (the “chicken”) want 25-50% coverage by the Energy Companies (the “egg”)
  - Maintenance of our aging infrastructure is expensive and expansion to meet growing demand faces opposition from many quarters
Flexibility of Use

• In the Transportation Sector
  – Desired range can be achieved with on-board hydrogen storage
  – Can be used in ICE (with modification, very low emissions); preferred for fuel cell (no emissions); APUs
  – Trains, automobiles, buses, and ships

• In the Buildings Sector
  – Combined heat, power, and fuel
  – Reliable energy services for critical applications
  – Grid independence

• In the Industrial Sector
  – Already plays an important role as a chemical
  – Opportunities for additional revenue streams
Proton Exchange Membrane Fuel Cells

- The PEM fuel cell was initially developed for the first Gemini spacecraft, but did not meet the reliability requirements of NASA.
- Development languished for decades, until improvements made at Los Alamos National Laboratory led to a resurgence of interest in the late 1980s and early 1990s.
- The centerpiece of the PEM fuel cell is the solid, ion-conducting polymer membrane.
  - Typically made from a tough, Teflon-like material invented by DuPont called Nafion™
    - This material is unusual in that, when saturated with water, it conducts positive ions but not electrons.
    - Exactly the characteristics needed for an electrolyte barrier.
The membrane is sandwiched between the anode and cathode electrode structures, which are porous conducting films, about 50 micrometers thick. The electrodes consist of carbon particles that have nanometer-size platinum particles bonded to them, in a porous matrix of recast Nafion™. The carbon particles provide the electron-conducting path, while the Nafion™ provides an ion-conducting path to the membrane.
In addition to having catalytic, electric- and ion-conducting properties, the electrodes and the supporting backing material are crucial to water management. This, and the control of gas flows in and out of the cell, are key to efficient cell operation:

- too little water at the cathode, the membrane begins to lose the ability to conduct ions.
- too much water, it floods the porous electrodes and prevents oxygen from diffusing to the catalytically active sites.
Public Acceptance

• We can succeed technically, but still fail if we don’t:
  – Involve the public early and often in the demonstration of new technologies
  – Inform the public about hydrogen and fuel cells in ways they can understand
  – Address safety concerns, real and imagined
A new source of power... called gasoline has been produced by a Boston engineer. Instead of burning the fuel under a boiler, it is exploded inside the cylinder of an engine...

The dangers are obvious. Stores of gasoline in the hands of people interested primarily in profit would constitute a fire and explosive hazard of the first rank. Horseless carriages propelled by gasoline might attain speeds of 14, or even 20 miles per hour. The menace to our people of this type hurtling through our streets and along our roads and poisoning the atmosphere would call for prompt legislative action even if the military and economic implications were not so overwhelming... the cost of producing (gasoline) is far beyond the financial capacity of private industry... In addition the development of this new power may displace the use of horses, which would wreck our agriculture.”
So – why hydrogen?

• It really is all about security
  – Energy security
    • Diverse domestic sources
    • Flexibility of system
  – Economic security
    • International leadership in technology development and deployment
    • Balance of payments
    • Price stability
  – Environmental security
    • Potential to meet GHG targets: with renewables or fossil with sequestration
    • Urban air quality improvements
    • Reduction in air pollutants
STEP ON THE HYDROGEN